International Council for the
Exploration of the Sea

ICES CM 2002/Q:05

Theme Session on Ocean-Shelf Sea Interactions:
Implications for Biology and Fisheries

The spatio-temporal pattern of hake *M. hubbsi* abundance and environmental influence in the Patagonian shelf area

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ABSTRACT

The Argentine hake (*Merluccius hubbsi*) is one of the most important fishery resources in the Southwest Atlantic. This species is widely distributed in the Patagonian shelf area and it is a major target species by international fleets in this South West Atlantic area. This paper presents results on the spatio-temporal distribution pattern of hake *M. hubbsi* abundance and environmental influence in the Patagonian shelf area. Spanish commercial fisheries data from 1989 to 1999 were used in the analysis. Data were collected by observers deployed by the IEO, Vigo (Instituto Español de Oceanografía, Vigo). The data include 15343 fishing haul records. CPUE (Catch Per Unit Effort, $kg \cdot hr^{-1}$) was used as an abundance index. The analyses of the general spatio-temporal pattern of fish abundance, and the influence of environmental factors, such as SST, SBT, depth, moon phase and cloud cover, on fish abundance and distribution, were based on correlation, variograms, and time-series maps created using GIS. Hake-targeted fishing by Spanish fleets was mainly focused on the shelf-edge area between 44.5°S – 47.0°S outside the Argentinean EEZ and in the area northwest of the Falkland Islands. The centre of high abundance is located in the shelf-edge area between 44.5°S – 47.0°S, particularly in the west part (i.e. in shallower waters) and in winter. The correlations between fish abundance and cloud cover are overwhelming negative, indicating that higher catches usually occur in cloudy weather conditions. In the major hake-targeted fishing area between 44.5°S – 47.0°S, the negative relationship between fish abundance and sea surface temperature in most months may suggest that high fish abundance is related to the strong northward cold Falklands current, and abundance is positively related to sea depth in summer.

Keywords: *hake, GIS, environment, spatio-temporal pattern*

INTRODUCTION

The Argentine hake (*M. hubbsi*) is one of the most important fishery resources in the Southwest Atlantic. *M. hubbsi* is widely distributed in the Patagonian shelf area. It makes up approximately two-thirds of total landings of all Argentinian fish catches (Podestá, 1989), and is a major target species for international fleets in the South West Atlantic area (FAO, 1996; Portela et al, 1998; Norbis et al, 1999). The Patagonia shelf area is an important fishing site for Spanish long-distance freezer fishing fleets. *M. hubbsi* is one of the major target species for Spanish fleets in this area (Portela et al, 1998). Previous studies reported that seasonal migration patterns, spawning and nursery areas in *M. hubbsi* are related to trophic interactions, reproduction, and changes in oceanographic conditions (Podestá, 1990; Ware, 1992).

During 2000-2001, the European Commission funded a study of the biology and fisheries of hake in the SW Atlantic. This paper presents results on the spatio-temporal distribution pattern of *M. hubbsi* abundance and environmental influence in the Patagonian shelf area. Spanish commercial fisheries data from 1989 to 1999 were used in analysis.

DATA AND METHODS

Spanish commercial fisheries data from 1989 to 1999 were used in the analysis. Data were collected by observers deployed by the IEO, Vigo (Instituto Español de Oceanografía, Vigo). The data include 15343 fishing haul records. Each records the catches of every species caught, fishing hours, start and end locations, fishing depth, sea temperature, day or night fishing, moon and cloud indices, wind strength and direction, surface roughness, etc. We calculated the ratio of *M. hubbsi* catches to total catches of all species for each haul, and defined the hauls as *M. hubbsi* targeted hauls if the ratio is equal to or greater than 0.5. *M. hubbsi* catches per unit effort (CPUE, $kg \cdot hr^{-1}$) by hauls were calculated and used as a fish abundance index in analysis.

Reynolds sea surface temperature (SST) data were downloaded from the NCAR (National Center for Atmospheric Research, USA) web site. The data are monthly average model results from remotely sensed data, survey temperature data, and sea ice distribution, with a spatial resolution of 1^{o} longitude by 1^{o} latitude (Reynolds and Marsico, 1993).

A geographical information system (GIS) was developed and used for visual analyses. It is based on ESRI (Environmental Systems Research Institute, Inc) GIS software ArcView®. Fishery and environmental data were integrated in the GIS as shapefiles. Long-term monthly mean CPUE from 1989 – 1999 and time-series monthly mean CPUE from January 1980 – December 1999, at spatial resolution of 0.3 degrees, were calculated based on the CPUE of single hauls. The results were integrated in the GIS as grids.

The investigations of the spatio-temporal pattern of fish abundance and environmental influence were carried out using both GIS-based visual analysis and statistical analysis methods. Based on time-series maps of fish abundance, high abundance centres, abundance distribution and temporal changes in abundance patterns were depicted. Visual analysis of the influence of environmental factors was carried out by displaying the environmental factors, in appropriate formats, for the same time period or previous (time-lagged) period, as background in maps.

In conjunction with visual analysis, quantitative analyses were also carried out. Correlograms were calculated using CPUE to investigate the spatial correlation of fish abundance with distance. The correlogram, $\rho(h)$, is a ratio of covariance and is defined as:

$$\rho(h) = \frac{C(h)}{C(0)} = 1 - \frac{\gamma(h)}{C(0)}$$

where $C(h)$ is the covariance for pairs of points separated by Euclidean distance h (the covariogram), $C(0)$ is the finite variance of the random field. The covariogram is defined as:

$$Cov(z_{i+h}, z_i) = C(h) \qquad \text{for all } i,\ i+h \in D$$

$\gamma(h)$ is the corresponding variogram and is calculated by:

$$\gamma(h) = \frac{1}{2\,|N(h)|} \sum_{N(h)} (z_i - z_j)^2$$

where $N(h)$ is the set of all pairwise Euclidean distance $i - j = h$, $|N(h)|$ is the number of distinct pairs in $N(h)$, and z_i and z_j are data values at spatial locations i and j, respectively.

The spatial relationships between fish abundance and environmental factors were calculated using Spearman's rank correlations and single month records of abundance, SST, SBT, SSS and SBS from 1989 – 1999, to quantify spatial correlations.

RESULTS AND DISCUSSION

Spatial and temporal abundance patterns

Figure 1 shows the locations of recorded hauls from 1989 – 1999. Spanish fleets fished in three separate areas: the north area (43° S), the middle area (46° S), and the south area, which is around Falkland Islands. Table 1 lists the recorded hauls in each area from 1989 – 1999. Of the three fishing areas, the south area around Falkland Islands is the major fishing site. Over half of total recorded hauls were carried out in this area. However, the middle area is the major *M. hubbsi* fishing site. Annually, over 50 percent of the total recorded hauls are targeted at *M. hubbsi*. In the *M. hubbsi* fishing season (March to October), almost all of recorded hauls in the middle area are targeted at *M. hubbsi*. The north area was a major hake fishing site before 1992, but after 1992, very few hauls were recorded in this area.

Figure 2 shows the locations of recorded hauls in different months over the period from 1989 – 1999, classified by the ratio of total *M. hubbsi* catches to the total catches of all species, by haul. Figure 3 illustrates the long-term monthly averaged CPUE ($kg \cdot hr^{-1}$), averaged by hauls, from 1989-1999, at a resolution of 0.3° longitude by 0.3° latitude. The highest CPUEs are recorded in the middle area and the west part of the south area.

As shown in Figure 4 and 5, the *M. hubbsi* fishing season is from March to October. Summer is the major *M. hubbsi* fishing season. *M. hubbsi* targeted hauls increased from February in both the middle and south areas. The *M. hubbsi* target fishing area also expands during the fishing season, particularly, in the south area. However, from October, *M. hubbsi* targeted hauls decreased and fishing area shrank. In the south area, fishing was focused within a very limited small area in October and there were no *M. hubbsi* target hauls in November. Similarly, in middle area, *M. hubbsi* targeted hauls were also focused in a smaller area from October than during the major fishing season.

The low correlation revealed in the spatial empirical correlograms of CPUE, as shown in Figures 6 and 7, indicate there is no significant spatial trend of fish abundance within the *M. hubbsi* targeted fishing area in either the south or middle areas.

Environmental influence on fish abundance and distribution

Moon and clouds: Table 2 lists the correlations between fish abundance and moon/cloud indices. Cloud cover is divided into 8 classes: 1 represents clear sky, 8 represents full cloudy sky. The lunar cycle is divided into 4 classes: 1 represents full moon, 4 represents new moon. The calculated correlations represent the relationship between CPUE and cloud index, at the same moon condition. Although there are only five significant negative correlation results, the correlations between fish abundance and cloud index at stages of the lunar cycle are overwhelming negative, indicating that higher catches were taken in cloudy weather conditions.

Sea Surface Temperature: Tables 3 and 4 list the correlations between *M. hubbsi* CPUE and sea temperature.

Although there is no clear relationship pattern between fish abundance and sea surface temperature over the whole area, fish abundance is negatively related to sea temperature in the middle area in most months. The negative correlation between fish abundance and SST in the middle area, as indicated by Podestá (1990), suggests that high abundance is related to the strong northward cold Falklands current (Malvinas current), which carries nutrient-rich water in this area. In contrast, as the south area is dominated by the Falklands current (Malvinas current), there is no clear relationship between SST and fish abundance. Figures 8 and 9 show fish abundance with SST background in 1990 and 1999, respectively. The patterns of SST contour lines depict the general near surface currents in the study area. By comparing the contour line patterns in these two figures, we can find that Falklands current (Malvinas current) was stronger in 1990 than in 1999, particularly in winter season, and fish abundance in middle area was higher in 1990 than in 1999.

Sea Depth: Table 5 lists the correlations between *M. hubbsi* CPUE and sea depth in whole area and each sub-area. The table shows that fish abundance is positively related to sea depth in summer.

ACKNOWLEDGEMENTS

This research was supported by EC funded project: CEC DG Fisheries Study Project nº 99/16.

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Table 1: Fishing hauls recorded by IEO (Spanish data: 1989 – 1999)

Area	Total hauls	Targetted at *M. hubbsi*	
		Hauls	%
North area	1151	164	14.2
Middle area	5474	2940	53.71
South area	8728	629	7.2
Total	15343	3733	24.3

Table 2: Spearman's rank correlation between *M. hubbsi* CPUE and cloud index (1- 8, 1 represents clear sky, 8 represents full cloudy sky) at different phases of the lunar cycle (moon index 1- 4, 1 represents full moon, 4 represents new moon). (*r: correlation, p: p-value, n: number of records).* Significant correlations (P<0.05) are indicated in bold face.

Moon		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	*r*	-	-	-	-0.11	-0.13	-0.19	**-0.30**	0.28	0	-	-	-
	p	-	-	-	0.70	0.69	0.55	**0.03**	0.08	0.99	-	-	-
	n	-	-	-	13	10	10	**52**	40	16	-	-	-
2	*r*	-	-	0	-	0.26	0.37	0.09	-0.11	**-0.66**	-	-	-
	p	-	-	0.97	-	0.34	0.14	0.44	0.37	**0.02**	-	-	-
	n	-	-	8	-	15	17	69	71	**14**	-	-	-
3	*r*	-	-	-0.14	0.57	-0.01	-0.19	0.06	**-0.27**	**-0.54**	-0.21	-	-
	p	-	-	0.68	0.06	0.97	0.32	0.65	**0.05**	**0.01**	0.57	-	-
	n	-	-	8	12	33	28	58	**52**	**26**	7	-	-
4	*r*	-	-	-	-0.14	-0.07	-0.05	**-0.35**	0.03	-0.08	-	-	-
	p	-	-	-	0.55	0.75	0.80	**0.01**	0.87	0.75	-	-	-
	n	-	-	-	18	24	30	**62**	39	15	-	-	-

Table 3: Spearman's rank correlation between *M. hubbsi* CPUE and SST. Single haul (hake targeted) data are used. (*r: correlation, p: p-value, n: number of records).* Significant correlations (P<0.05) are indicated in bold face.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Whole	*r*	-	-0.12	-0.04	-0.06	-0.01	-0.25	**0.08**	0.26	0.08	-0.18	0.21	-
	p	-	0.65	0.62	0.25	0.89	0	**0.03**	0	0.16	0.10	0.18	-
	n	-	14	137	398	396	370	**844**	651	287	90	42	-
North	*r*	-	-	-	-	**0.31**	-0.14	-0.09	-	-	-	-	-
	p	-	-	-	-	**0.03**	0.19	0.76	-	-	-	-	-
	n	-	-	-	-	**51**	86	13	-	-	-	-	-
Middle	*r*	-	-0.16	-0.06	-0.05	**-0.13**	**-0.25**	**-0.18**	**0.15**	0.07	-0.09	0.21	-
	p	-	0.58	0.48	0.33	**0.02**	**0**	**0**	**0**	0.42	0.47	0.18	-
	n	-	12	130	361	**310**	**257**	**691**	**491**	137	61	42	-
South	*r*	-	-	0.36	-0.01	0.14	**-0.51**	0.11	**0.22**	0.15	-0.03	-	-
	p	-	-	0.54	0.97	0.42	**0.01**	0.20	**0.01**	0.06	0.87	-	-
	n	-	-	5	37	35	**27**	140	**160**	150	29	-	-

Table 4: Spearman's rank correlation between *M. hubbsi* CPUE and SBT. Single haul (hake targeted) data are used. (*r: correlation, p: p-value, n: number of records).* Significant correlations (P<0.05) are indicated in bold face.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Whole	*r*	-	0.05	**0.52**	**-0.17**	-0.04	**-0.25**	**-0.26**	**-0.33**	-0.24	-0.37	-	-
	p	-	0.92	**0.03**	**0.02**	0.64	**0.04**	**0**	**0**	0.09	0.16	-	-
	n	-	8	**18**	**196**	150	**63**	**115**	**89**	50	15	-	-
North	*r*	-	-	-	-	**0.33**	**0.54**	0.15	-	-	-	-	-
	p	-	-	-	-	**0.09**	**0.05**	0.79	-	-	-	-	-
	n	-	-	-	-	**27**	**14**	6	-	-	-	-	-
Middle	*r*	-	0.05	0.53	**-0.19**	0.08	-0.19	**-0.39**	-	-	-	-	-
	p	-	0.92	0.07	**0.01**	0.41	0.27	**0**	-	-	-	-	-
	n	-	8	13	**187**	114	36	**97**	11	9	-	-	-
South	*r*	-	-	-	0.39	0.39	-0.05	0.30	**-0.40**	-0.21	-	-	-
	p	-	-	-	0.29	0.27	0.85	0.32	**0**	0.18	-	-	-
	n	-	-	-	9	9	13	12	**78**	41	13	-	-

Table 5: Spearman's rank correlation between *M. hubbsi* CPUE and depth. Single haul (hake targeted) data are used (FIFD 01/88-04/01, IEO 01/89-12/99). (*r: correlation, p: p-value, n: number of records).* Significant correlations ($P<0.05$) are indicated in bold face.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Whole	*r*	-	0.47	0	**0.14**	**-0.19**	0.03	**-0.28**	**-0.36**	0	0.20	0.01	-
	p	-	0.07	0.99	**0**	**0**	0.53	**0**	**0**	0.97	0.06	0.97	-
	n	-	16	153	**466**	**400**	396	**923**	**708**	288	90	42	-
North	*r*	-	-	-	-	0	**0.34**	-0.45	-	-	-	-	-
	p	-	-	-	-	0.99	**0**	0.12	-	-	-	-	-
	n	-	-	-	-	51	**86**	13	-	-	-	-	-
Middle	*r*	-	0.12	0.06	**0.13**	**-0.31**	-0.09	**-0.09**	**-0.20**	-0.16	-0.11	0.01	-
	p	-	0.70	0.45	**0.01**	**0**	0.12	**0.01**	**0**	0.06	0.38	0.97	-
	n	-	12	146	**428**	**314**	282	**762**	**526**	137	61	42	-
South	*r*	-	-	-0.30	0.14	0.09	-0.26	0.05	-0.05	0.03	0.16	-	-
	p	-	-	0.48	0.39	0.61	0.18	0.51	0.50	0.71	0.40	-	-
	n	-	-	5	38	35	28	148	182	151	29	-	-

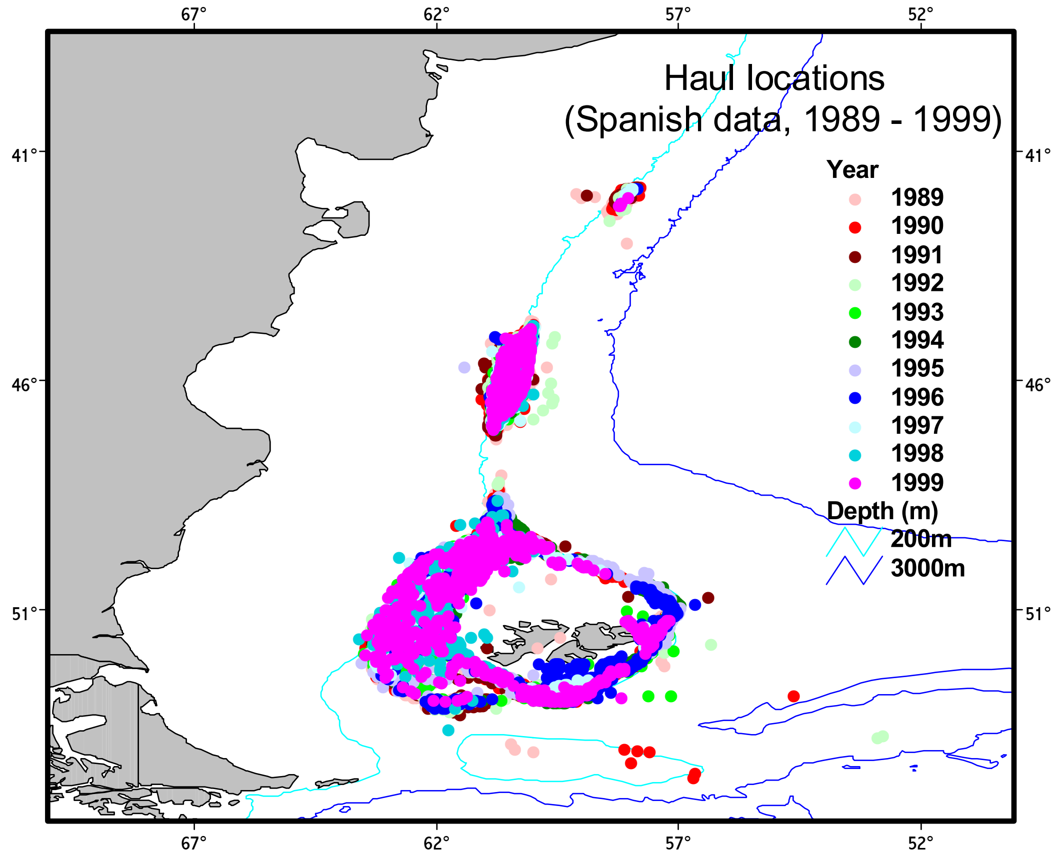

Figure 1: The locations of recorded hauls from 1989 – 1999.

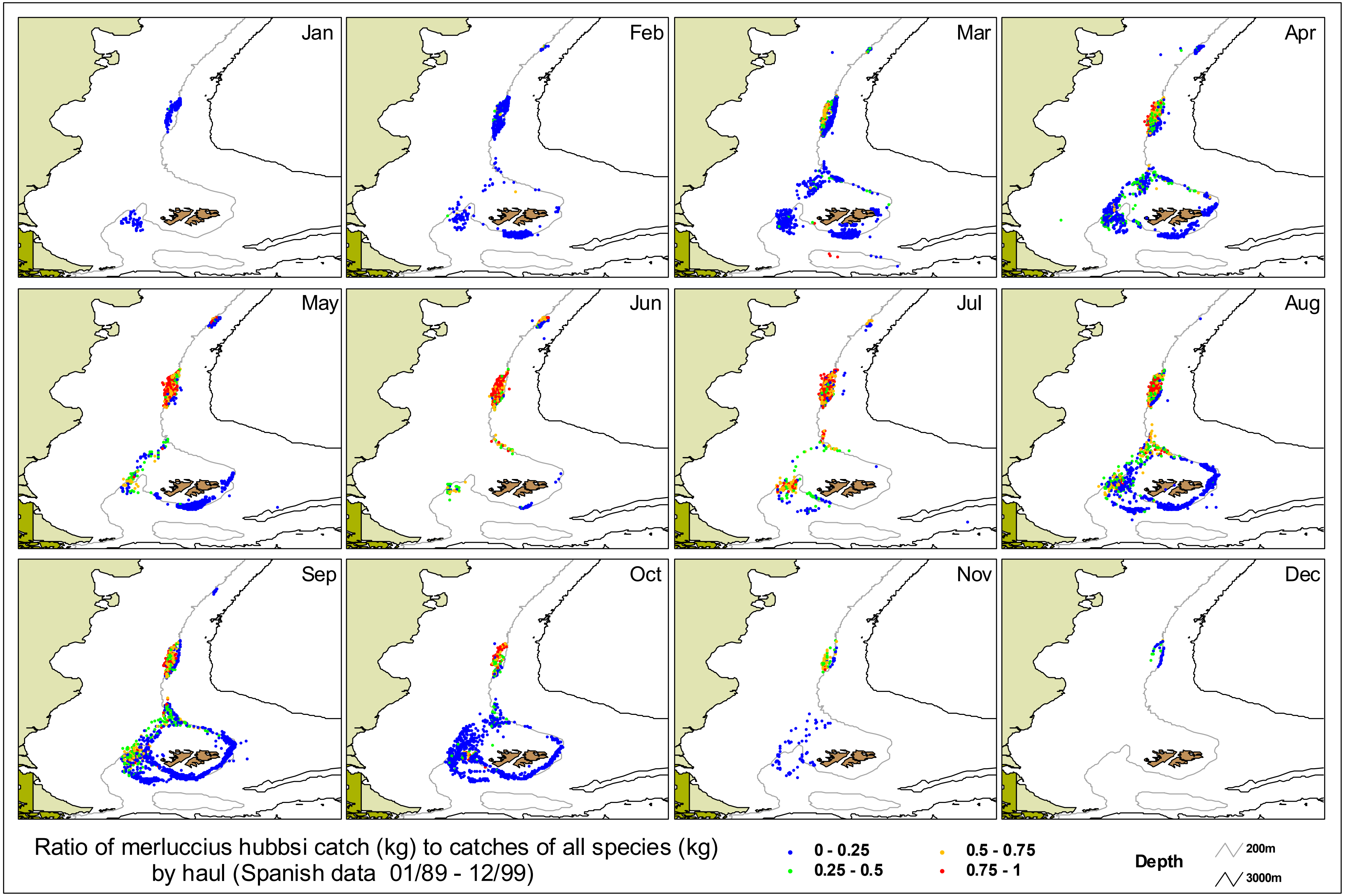

Figure 2: The locations of recorded hauls over 1989-1999, classified by the ratio of total *M. hubbsi* catches to the total catches of all species. The hauls with the ratio >=0.5 are defined as *M. hubbsi* targeted.

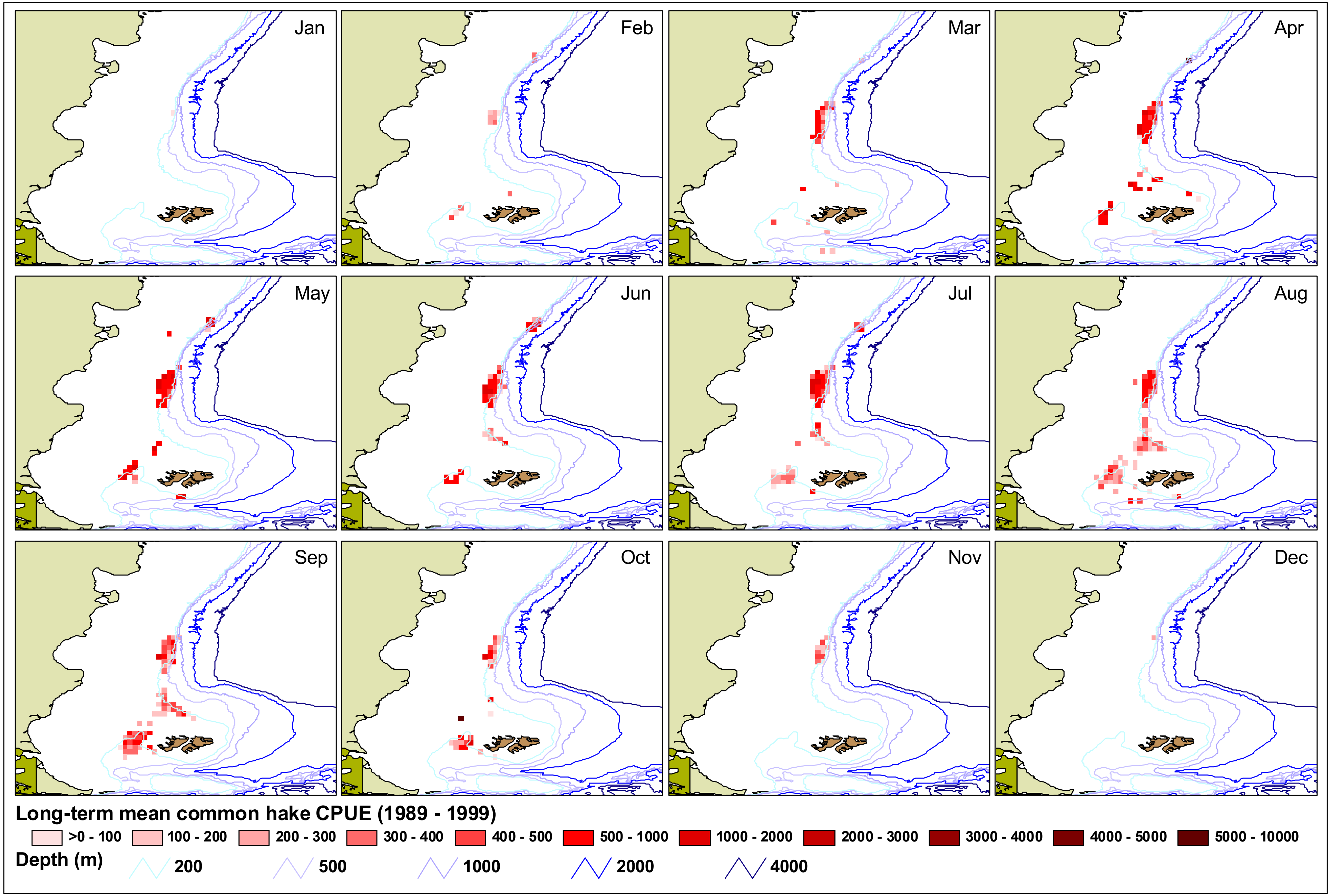

Figure 3: Long-term averaged CPUE (kg·hr^{-1}) calculated from single hauls from 1989 – 1999 at 0.3 by 0.3 degree resolution.

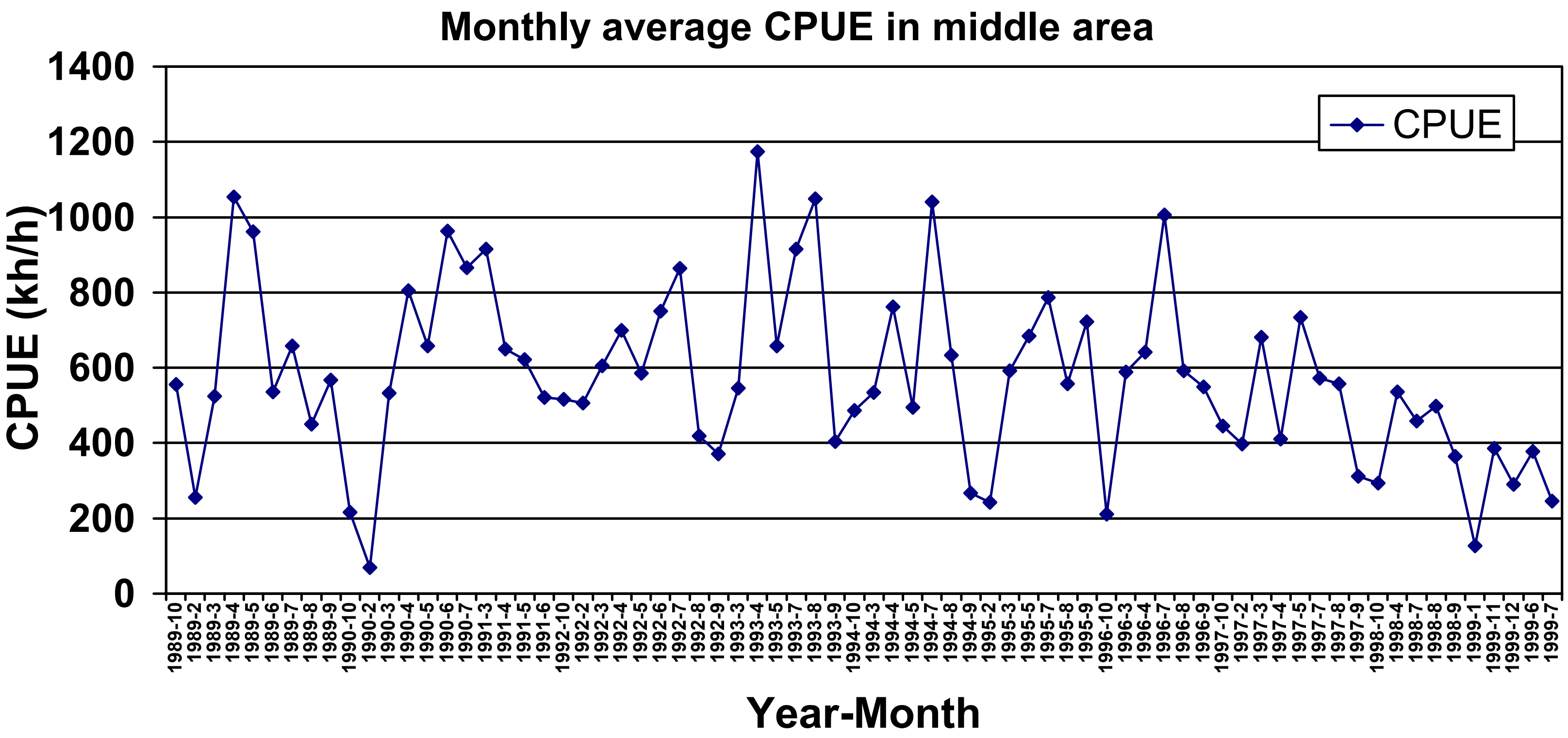

Figure 4: Monthly averaged CPUE (kg·hr^{-1}) calculated from single hauls from 1989 – 1999 in the middle area

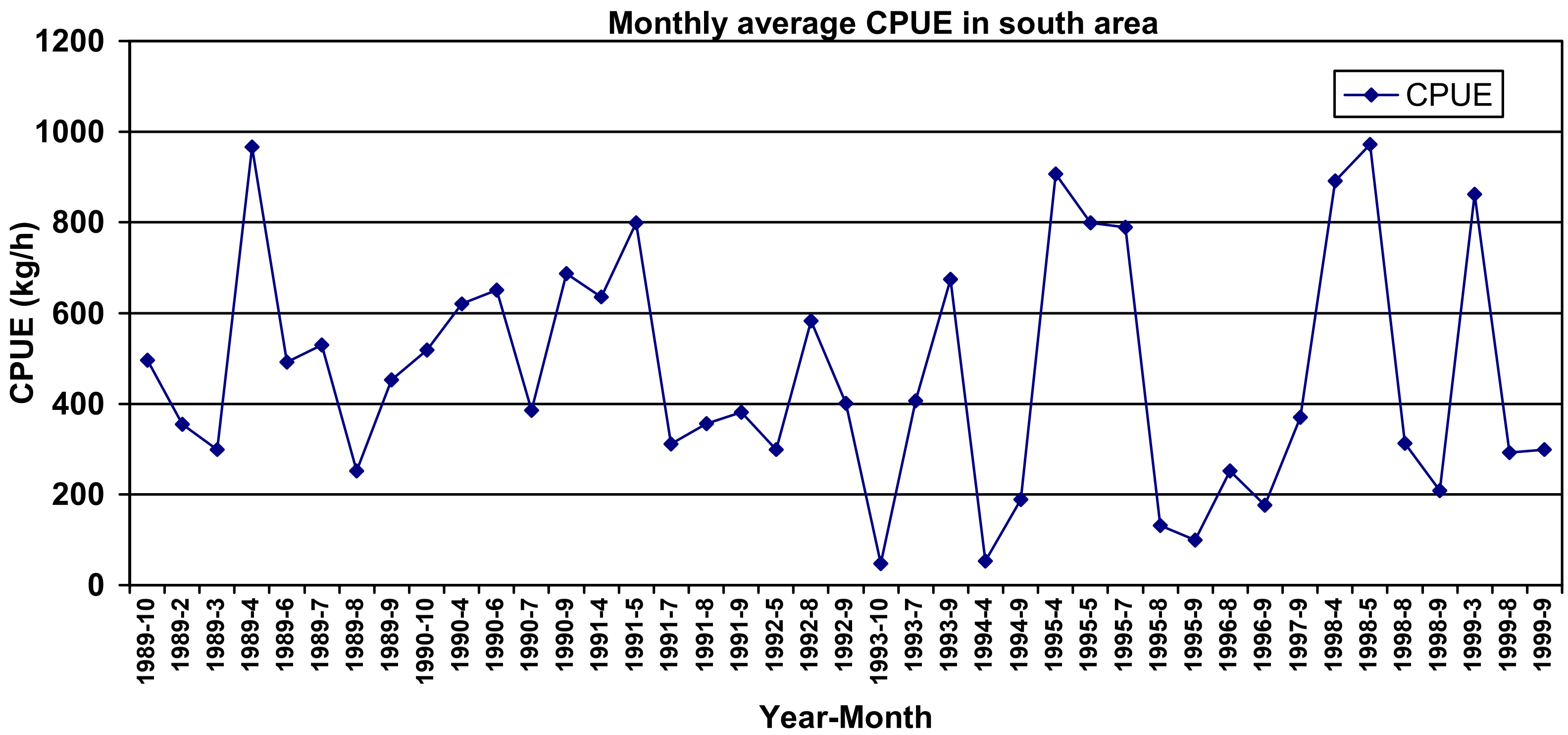

Figure 5: Monthly averaged CPUE (kg·hr^{-1}) calculated from single hauls from 1989 – 1999 in the south area.

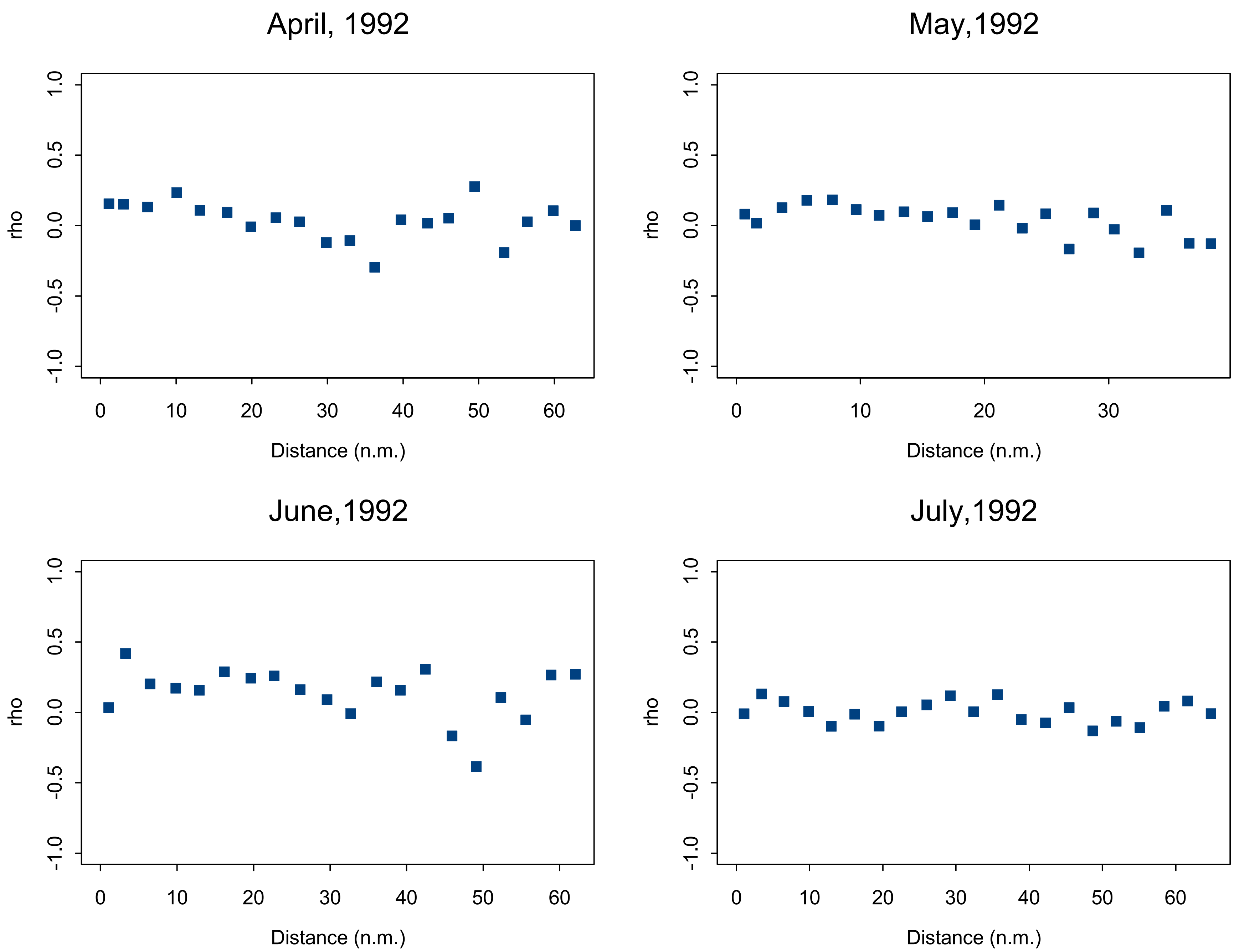

Figure 6: Spatial correlograms (rho) calculated using middle area haul CPUE data in the middle area in Aril, May, June and July, 1992.

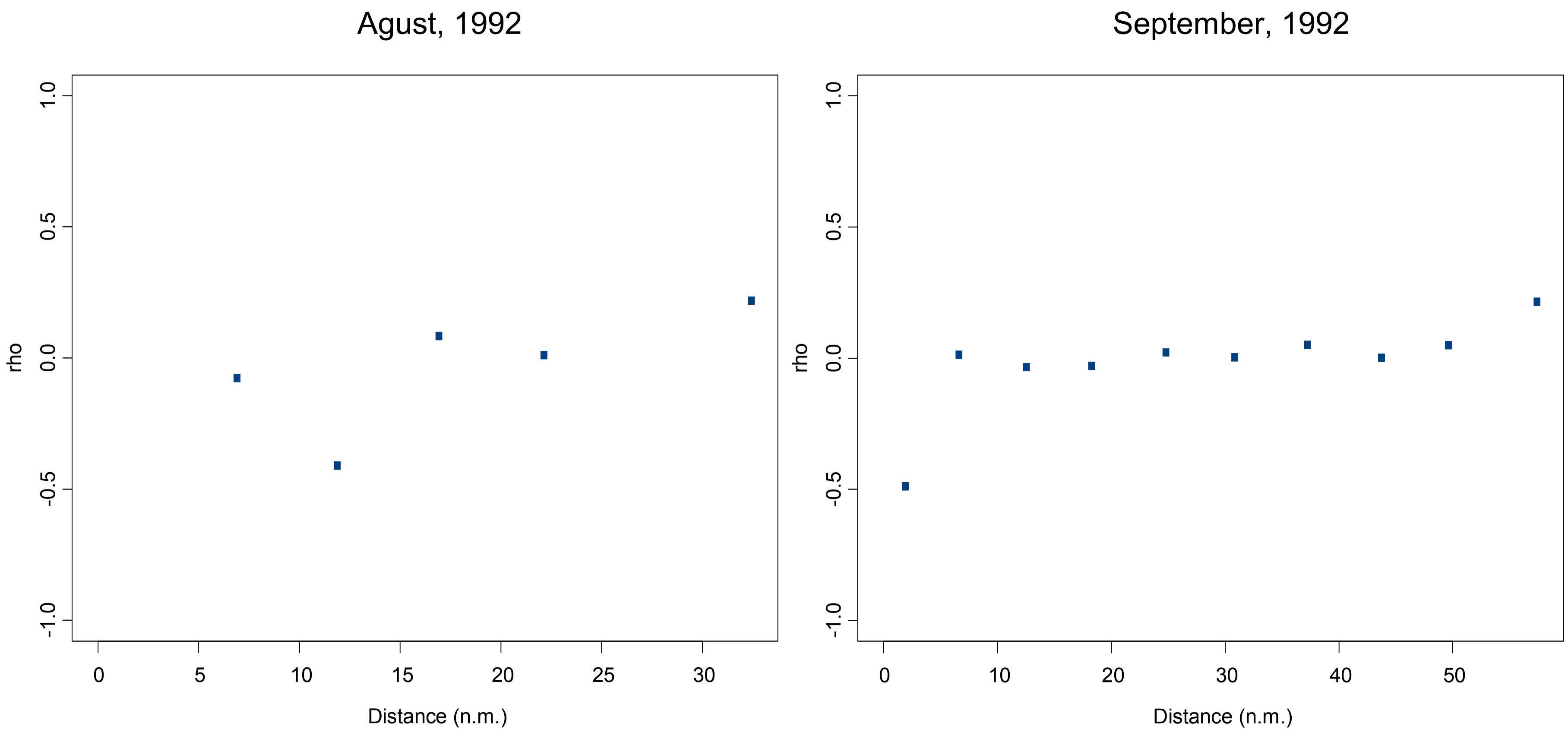

Figure 7: Spatial correlograms (rho) calculated using south area haul CPUE data in August and September, 1992.

Monthly average CPUE (Common Hake, Merluccius hubbsi) and SST (1990)

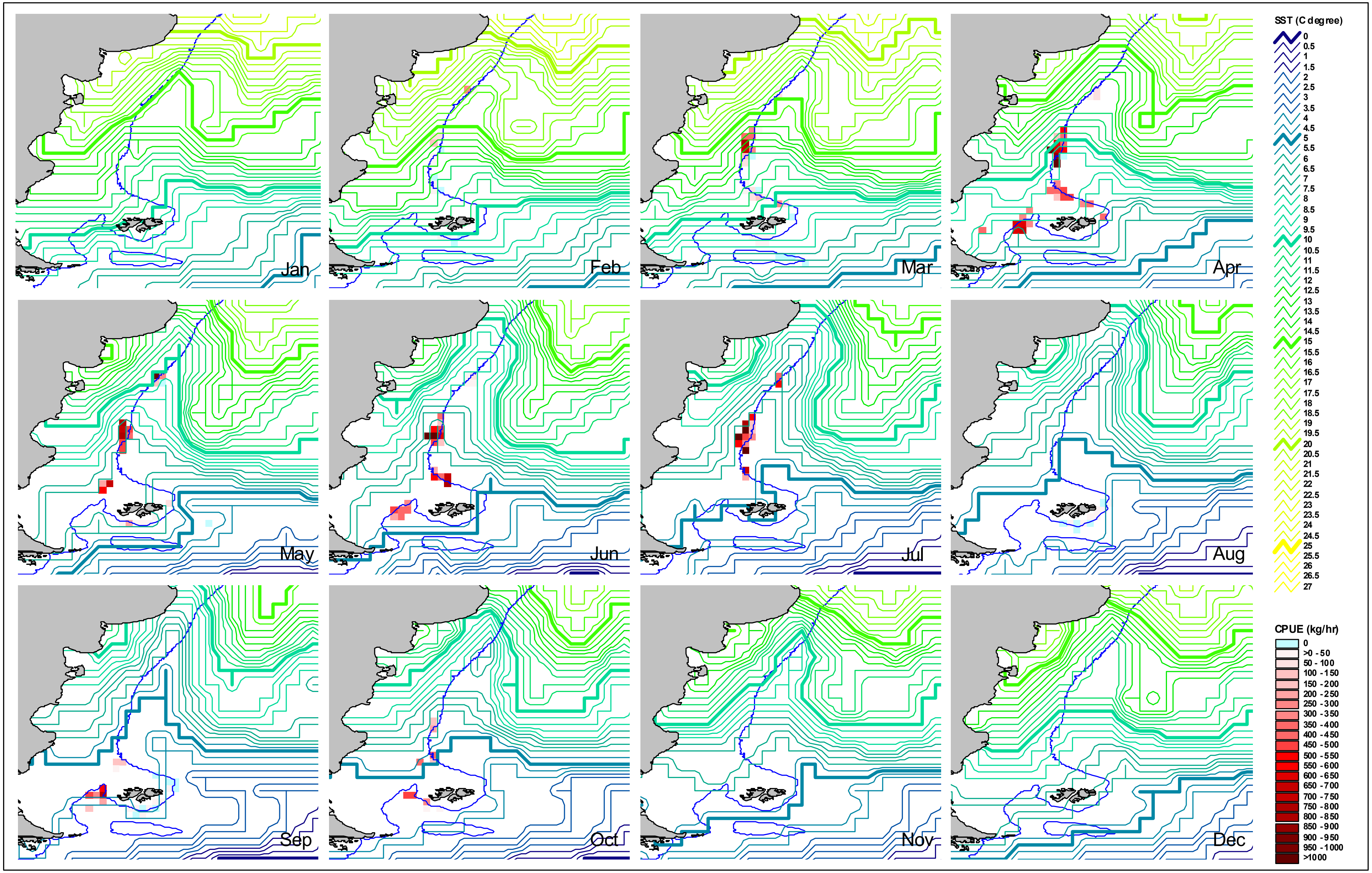

Figure 8: Monthly averaged fish abundance calculated using single haul CPUE with SST background in 1990

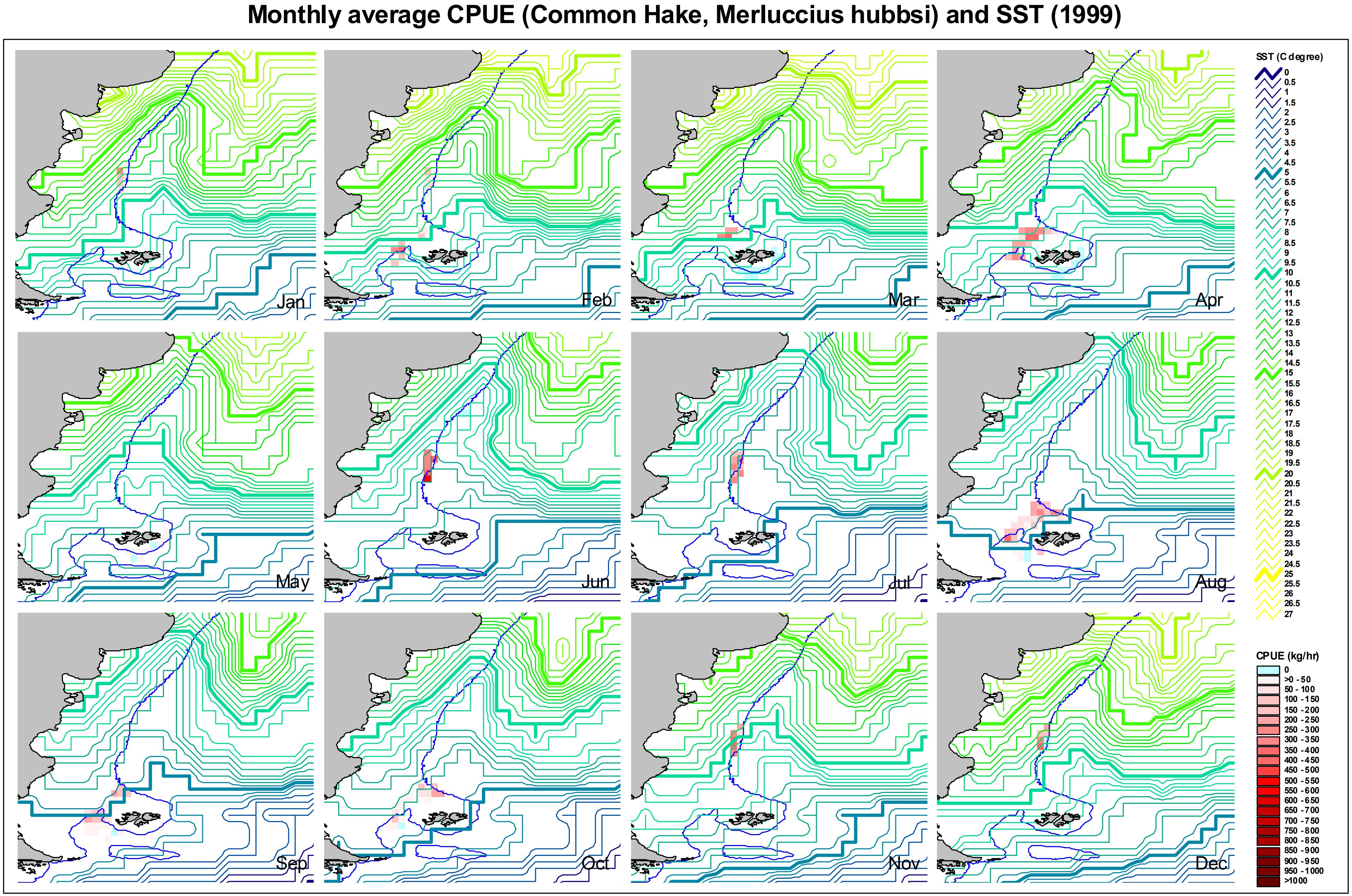

Figure 9: Monthly averaged fish abundance calculated using single haul CPUE with SST background in 1999